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SHORT REPORT / COMMUNICATION BRÈVES

Cluttered Environments: Differential Effects of Obstacle Position on Grasp and Gaze Locations

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Previous research has investigated the effects of nontarget objects (NTOs) on reach trajectories, but their effects on eye-hand coordination remain to be determined. The current investigation utilized an eye-hand coordination paradigm, where a reaching and grasping task was performed in the presence of an NTO positioned exclusively in the right or left workspace of each right-handed participant. NTOs varied in their closeness to the subject and reach-path, between the starting location of the hand and the target-object of the reach. A control condition, where only the target was present, was also included. When an NTO was presented on the right (ipsilateral to the reaching hand), it pushed the final grasp and gaze locations on the target, shifting them to the left—away from the "obstacle." The impact of the ipsilateral NTO was increased as it was moved into positions closer to the participant that were of greater obstruction to the hand and arm. In contrast, when the NTO was contralateral, the risk of collision was low and participants developed a set reach plan that was repeated nearly identically for each contralateral NTO position. Our findings also indicate that the "invasiveness" of the NTO positions had a greater effect on grasp than it did on gaze position—demonstrating how the arrangement of clutter in an environment can differentially affect gaze and grasp when reaching for an object.

Keywords: vision, gasping, perception and action, eye-hand coordination, attention

When reaching for objects, our hand and arm rarely collide with nontarget objects (NTOs), even if our workspace is cluttered. This process requires a complex interplay between incoming visual information, which codes the position of potential obstacles, and the visuomotor system controlling the execution of the reach (Chapman & Goodale, 2008, 2010; Dean & Brüwer, 1994). When reaching out to touch a target with two obstacles present (to the left and right of the reaching arm), Chapman and Goodale (2008) found that participants would bisect the obstacles in a way that brought the hand and arm furthest away from both obstacles, even if shorter reaches were possible with a hand position closer to one of the obstacles. Both Dean and Brüwer (1994) and Chapman and Goodale (2008, 2010) demonstrated that obstacles ipsilateral to the reaching arm produce greater impacts on the mechanics of a reach, creating reaches of a slower velocity and with greater trajectory deviations around obstacles when compared to those in the contralateral space. Because the hand and arm must be brought past ipsilateral obstacles, a greater minimum distance from the obstacle is needed to avoid collision, while other reach mechanics are attenuated to ensure more control during the action. Similar effects are seen when obstacles are closer to the participant or the target (Tresilian, 1998) as, like ipsilateral obstacles, they are more likely to cause collisions. Conversely, obstacles beyond the target (Mon-Williams, Tresilian, Coppard, & Carson, 2001) or below the reach path (Verheij, Brenner, & Smeets, 2014) have no impact on reaching, as there is little possibility of collision. Missing from these investigations, however, is an exploration of the role that gaze plays in obstacle avoidance.

The eyes are known to guide the hand through space, bringing task relevant visual information to the motor system in order to determine the best possible plan of action (Johansson, Westling, Backstrom, & Flanagan, 2001). Previous research in our labouratory has shown that the eyes tend to be directed toward the eventual location of the index finger on the object (Bulloch, Prime, & Marotta, 2015; Desanghere & Marotta, 2011, 2015; Prime & Marotta, 2013). Gaze prioritizes locations where the hand is about to be rather than focusing on the hand itself, allowing the motor system to adapt to any task relevant changes in the environment. Gaze acts to bring behaviourally relevant information to the motor system as it is needed (Hayhoe, 2000). In this light, obstacles may be seen as salient distractors (Tipper, Howard, & Jackson, 1997), drawing attentional resources away from the target, and toward the obstacle, as they become more behaviourally relevant to the task. This opens the possibility of gaze and grasping being differentially affected by the presence of obstacles.

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In the current study, participants performed reaches around obstacles exclusively ipsilateral or contralateral to their reaching arm, positioned at one of six potential locations. It was hypothesised that the more "intrusive" ipsilateral objects, those in closer proximity to the reaching hand, would result in greater shifts in both final grasp and gaze positions. However, we also anticipated that the effects of obstacles on gaze and grasp may not be equivalent, not only due to the possibility of obstacles drawing attentional resources but also because the motor system would be primarily concerned with preventing the hand and arm, not the eye, from colliding with an obstacle.

Method

Participants

Twenty right-handed undergraduate students (seven male, 13 female; average age 21.1 years) were recruited from the University of Manitoba's psychology participant research pool and received course credit for their participation. Participants were screened for handedness using a modified version of the Edinburgh Handedness Inventory (Oldfield, 1971). The research complies with American Psychological Association ethical standards in the treatment of participants and was approved by the Psychology/Sociology Research Ethics Board of the University of Manitoba.

Materials

Reaches were recorded using an Optotrak Certus three-dimensional recording system (150 Hz sampling rate, spatial accuracy up to .01 mm; Northern Digital, Waterloo, ON, Canada). Two infrared light emitting diodes (IREDS) were fastened to a participant's right index finger (positioned on the left side of the cuticle) and another two IREDs were attached to the thumb (positioned on the right side of the cuticle). A Velcro watchband was attached to the participant's right wrist, which held two IREDS 5 cm above the wrist. An EyeLink II head-mounted eye tracking system (250 Hz sampling rate, spatial resolution <0.5°; SR Research Ltd., Mississauga, Ontario, Canada) was used to record binocular eye movements, which was calibrated using a computer-displayed 9-point calibration/validation procedure. To ensure the eye-tracker was accurately calibrated to less than 1 cm (approximately 1°) error, accuracy checks were performed at the beginning and end of each block of trials. This was accomplished by having participants fixate on a dot at the centre of the monitor and comparing the position of their fixation to the position of the dot. MotionMonitor software (Innovative Sports Training, Inc., Chicago, IL) was used to integrate eye, head, and hand data into a common spatial and temporal frame of reference sampled at 130 Hz.

Participants reached to grasp a target object on each trial, which could be one of three white foam-core Efron shapes (Efron, 1968; A [8 × 8 cm], B [10 × 6.5 cm], or C [15 × 4.5 cm]), mounted on a black board 40 cm above the table, 55 cm from the participant, and 35 cm from the starting location of the hand. Two additional blocks (9 × 7 cm, 12 × 5.5 cm) were presented as targets on occasion, to increase the number of target objects seen by the participants, in order to prevent them from "ballparking" the size of the target. No analysis was performed on these additional distractor targets. NTOs, which served as potential obstacles in the grasping space, were white foam-core rectangular blocks, 50 cm in height, 5 cm in width, and 0.5 cm in depth. On any trial, an NTO could be located at any one of six possible positions in the three-dimensional grasping space, defined as the conjunction points between three depths from the starting position (10 cm, 17 cm, 24 cm) and two horizontal positions from the midline between the starting position of the hand and the target (7 cm, 10 cm; Figure 1A).

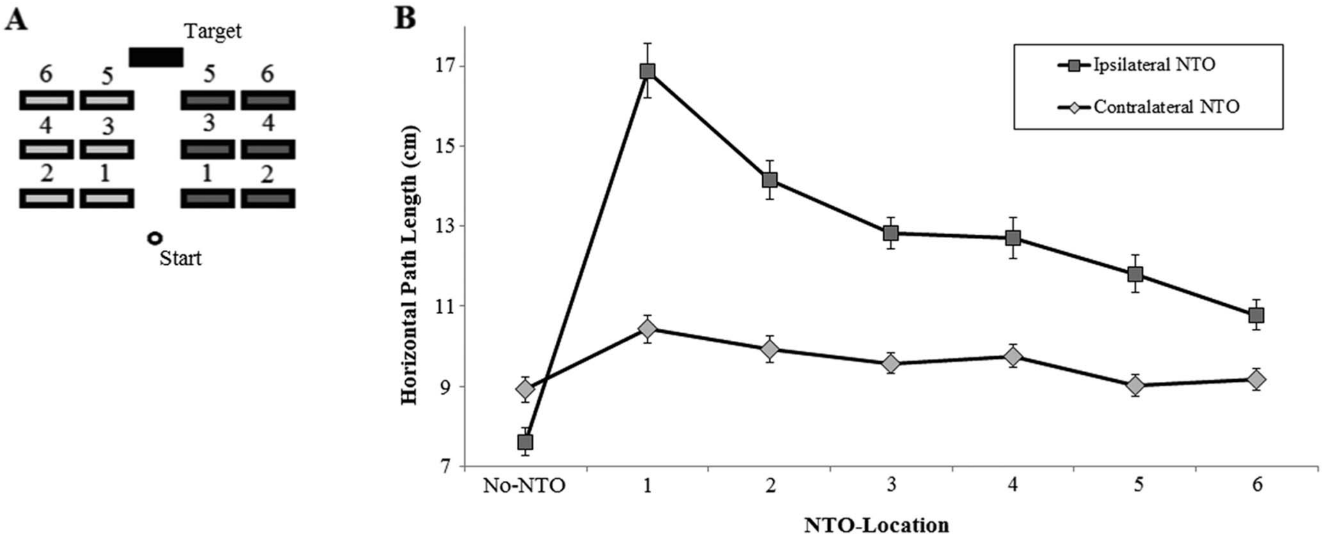

Figure 1. (A) A not-to-scale schematic of potential nontarget object (NTO) locations, both ipsilateral (right—dark grey) and contralateral (left—light grey) to the participant's reaching hand. A seventh no-NTO condition was also randomly included among trial blocks. (B) Wrist deviation across NTO location for contra- and ipsilateral NTOs. Error bars represent standard error of the mean.

Procedure

Participants were instructed to reach out and grasp the target as quickly, but naturally, as possible with their right hand, while avoiding collision with the NTO. Participants were not instructed about where on the target to grasp it. For each participant, NTOs appeared only ipsilateral or contralateral to their right hand. On some trials the NTO was not present; these trials acted as a control condition. Experimental trials were randomly divided into four blocks. In a full experiment, a participant would reach 12 times in each of the seven NTO-location conditions (six NTO positions and one no-NTO control), four times to each of the three targets in each NTO location. Additionally, each distractor target was positioned in each of the NTO locations, for a total of 98 trials. Three practice trials were completed before beginning the experiment to acquaint participants with the task.

Results

Data Analysis

For each dependent variable, a 2 × 7 × 3 mixed-model repeated-measures analysis of variance was performed investigating the main effects of the between-subjects variable NTO side (2), and of the within-subject variables of potential NTO location (6 NTO locations + 1 no-NTO control) and target object (3). Post hoc Tukey's honest significant difference test were performed where necessary.

Horizontal path length. The horizontal path length represents the total distance the hand moved in the horizontal plane during a reach. Main effects of NTO side, $F(1, 18) = 12.21$, $p = .003$, NTO location, $F(4.76, 85.43) = 67.07$, $p = .001$, and target, $F(2, 36) = 5.48$, $p = .008$, were found. An NTO Side × Location, $F(4.76, 85.43) = 33.17$, $p = .001$, interaction was also found to be significant (see Figure 1B).

When the NTO was contralateral, there were no differences in participants' performances with two exceptions: Contralateral NTOs in location 1 produced greater horizontal path lengths than did the control condition ($p < .01$) or NTOs in location 5 ($p < .05$). In all cases, the presence of an ipsilateral NTO produced reaches that deviated a greater distance than the control condition (all $p < .01$). Longer horizontal path lengths were produced at every ipsilateral NTO location condition than contralateral position ($p < .01$), except the control condition, which showed the opposite pattern ($p < .05$).

The effect of NTO depth was evident in the greater path lengths present when the NTO was closest to the reaching hand, location 1, over further locations 3 or 5 (all $p < .01$), location 2 over locations 4 and 6 (all $p < .01$) and location 4 over location 6 ($p < .01$). The effect of the horizontal position of the NTO was demonstrated with reaches that deviated a greater distance when the NTO was in location 1, than the more lateral location 2 ($p < .01$).

A Target main effect suggests that participants generated longer horizontal hand paths when reaching to the tallest Target A, than the shorter and wider Targets B and C (Target A: $M = 11.33$ cm; B: $M = 10.87$ cm; C: $M = 10.7$ cm). As this appears to be a mechanical effect of block size on reach, and not related to our NTO manipulation, it will not be discussed further.

Index grasp position. The contact position of the index finger on the target relative to its horizontal midpoint was calculated. Main effects of NTO side, $F(1, 18) = 15.46$, $p = .001$, NTO location, $F(3.32, 59.82) = 8.59$, $p = .001$, and target, $F(1.19, 21.36) = 11.15$, $p = .002$, were found. Significant interactions of NTO Side × Location, $F(3.32, 59.82) = 7.96$, $p = .001$, and NTO Side × Target, $F(1.19, 21.36) = 7.65$, $p = .009$, were also found. In all cases, when the NTO was contralateral to the reaching hand, grasp positions did not differ from the control nor between NTO locations (all $p > .05$). In contrast, the presence of an ipsilateral NTO consistently produced leftward shifts in grasp location on the target greater than the control condition (all $p < .01$). Location of the ipsilateral NTO also had an effect, with the nearest outer position (2) producing greater shifts in grasp position than the farthest outer location (6; $p < .01$). Each ipsilateral NTO produced a greater shift in grasp location than did its contralateral opposite (all $p < .01$), with the exception of the control condition, which did not differ based on NTO side ($p > .05$; see Figure 2).

For the NTO Side × Target interaction, when the NTO was contralateral, participants produced a more rightward grasp location as the target became wider and shorter (Block A = −0.27 cm, Block B = 0.36 cm, Block C = 0.92 cm; all $p < .01$). This effect was not seen when the NTO was ipsilateral (all $p > .05$), suggesting the shift in grasp produced by the presence of ipsilateral NTOs overshadowed any differences due to target shape.

Gaze position. Gaze coordinates were recorded for the full duration of each trial and were characterised into fixations based on a dispersion algorithm (Salvucci & Goldberg, 2000), with a minimum duration threshold of 100 ms and a maximum dispersion threshold of 1 cm (approximately 1°). The first recorded position in a fixation period was reported as the fixation coordinates. The dispersion limit is typically only exceeded during a saccadic movement. Gaze positions were calculated at an assumed depth equal to that of the distance between the participant and the target object (55 cm). Gaze location was calculated as the average between the position of the left and right eye at the depth of the target.

Throughout the reach, participants almost exclusively fixated on the target, with only 19 of 3,847 total fixations across all participants off the target object (0.49%). Since the NTOs did not appear to be an active target for fixation, participants fixated on the target object prior to and throughout the reach, we focused our efforts on the final fixations on the target objects and how they related to the final grasp locations (Bulloch et al., 2015; Desanghere & Marotta, 2011, 2015; Prime & Marotta, 2013). Analysis of the final fixation, revealed main effects of NTO side, $F(1, 18) = 9.89$, $p = .006$, and NTO location, $F(4.1, 73.86) = 3.46$, $p = .011$. The NTO Side × Location, $F(4.1, 73.86) = 2.51$, $p = .048$, and NTO Side × Target, $F(1.54, 27.64) = 5.05$, $p = .020$, interactions were also found to be significant. In all cases, when the NTO was contralateral, there were no differences in performance (all $p > .05$). In all cases, the presence of an ipsilateral NTO produced leftward shifts in the location of the final fixation when compared to the control condition (all $p < .01$; see Figure 3). No effects of NTO proximity to the reach or participant were seen (all $p > .05$). Leftward shifts in fixation location were seen at every ipsilateral NTO location compared to the contralateral (all $p < .01$), with the exception of the control condition, which did not differ based on NTO side ($p > .05$). This pattern of results is nearly identical to the effect seen on the index finger grasp location from ipsilateral NTOs. In line with the results from the grasp location analysis, as the target object became shorter and wider, final gaze position shifted to the right,

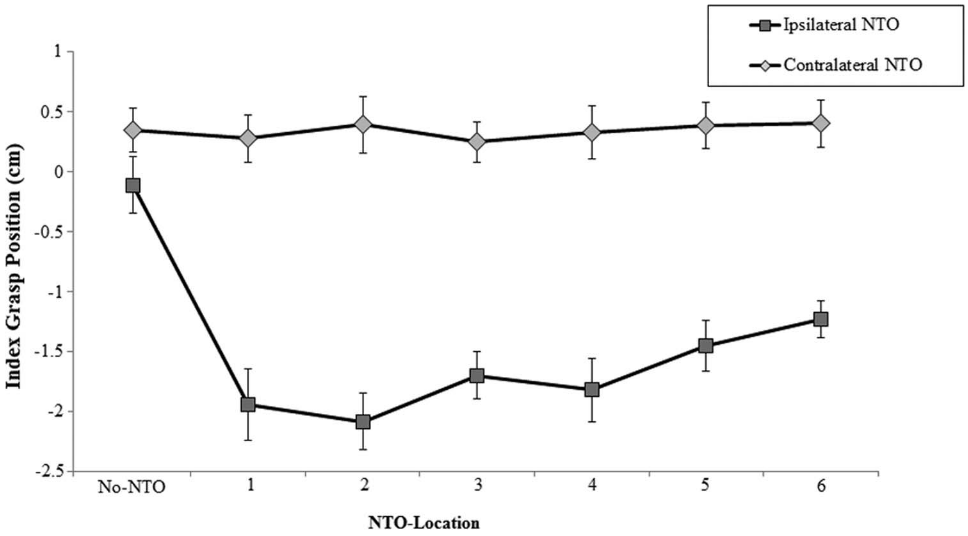

Figure 2. The average index grasp position across nontarget object (NTO) location for contra- and ipsilateral NTOs relative to target object's centre of mass designated as zero. Negative means are to the left of the centre of mass, while positive means are to the right. Error bars represent standard error of the mean.

however only in the presence of contralateral NTOs (Block A = −0.03 cm, Block B = 0.15 cm, Block C = 0.56 cm; all at least $p < .05$).

Distance between horizontal index grasp position and final gaze fixation. This variable is a measure of the distance between the index grasp point and the final gaze fixation location in the horizontal plane. Previous work in our lab has always shown a tight correlation between grasp and gaze when grasping target blocks in an uncluttered environment (Desanghere & Marotta, 2011, 2015; Prime & Marotta, 2013; Bulloch et al., 2015). A main effect of target (Target A: $M = -0.5$ cm; B: $M = -0.12$ cm; C: $M = -0.07$ cm), $F(1.63, 29.33) = 10.62$, $p = .001$, was found. An NTO Side × Location, $F(6, 108) = 2.29$, $p = .041$, interaction was also found to be significant (see Figure 4). When the NTO was ipsilateral to the participant and positioned in locations 1, 2, or 4, grasp location was significantly to the left of final gaze fixation (all $p < .05$). No difference in the distance between final gaze fixation and grasp location were found between contralateral NTOs (all $p > .05$). These findings suggest that gaze fixation may be less sensitive to shifts resulting from the presence of ipsilateral NTOs than is grasp location on the target.

Discussion

Extending on the work by Dean and Brüwer (1994) and Chapman and Goodale (2008, 2010), ipsilateral (right side) NTOs were

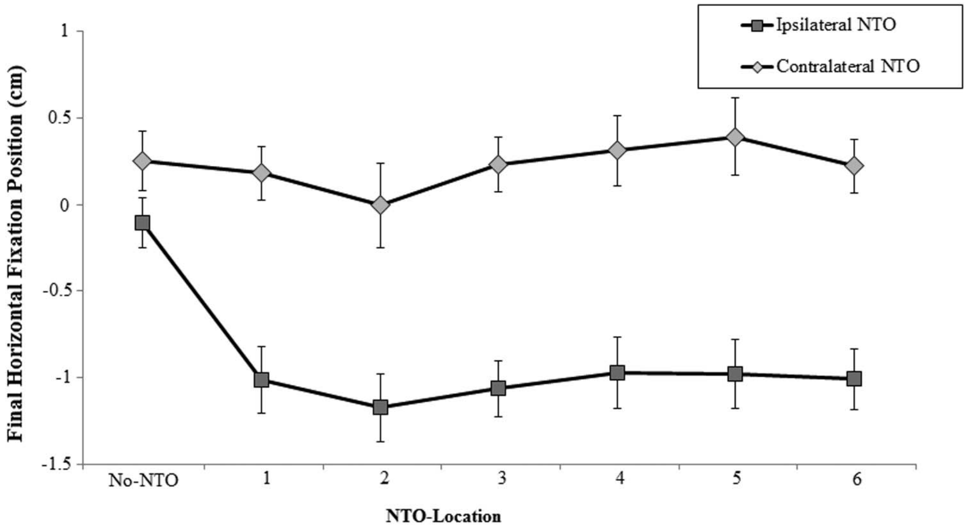

Figure 3. The average horizontal position for final fixation across nontarget object (NTO) location for contra- and ipsilateral NTOs relative to target's centre of mass designated as zero. Negative means are to the left of the centre of mass, while positive means are to the right. Error bars represent standard error of the mean.

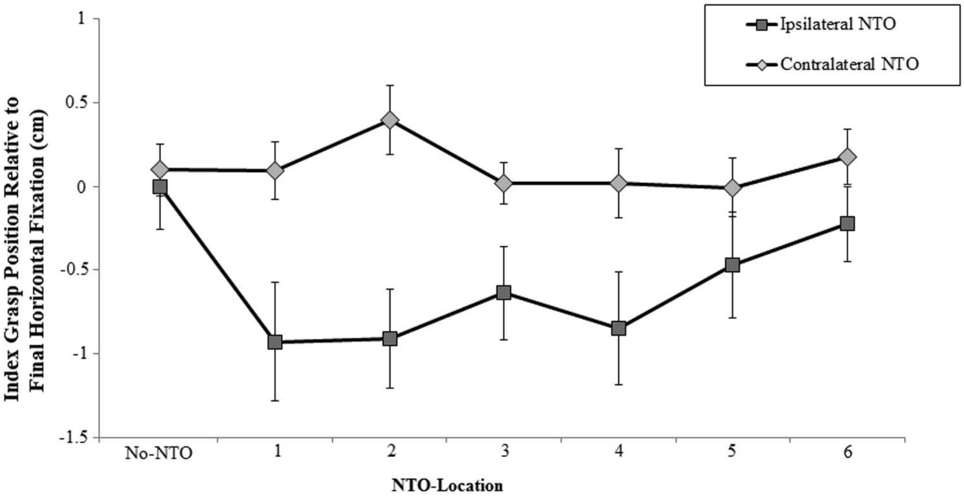

Figure 4. The average horizontal difference between index finger grasp position and final fixation position across nontarget object (NTO) location for contra- and ipsilateral NTOs. Negative values are to the left of the final horizontal fixation, while positive values are to the right. Error bars represent standard error of the mean.

found to "push" not only index grasp location but also gaze fixations leftward, away from their position, whereas contralateral NTOs produced reaches and gaze fixations that were largely identical to those performed in the absence of NTOs. The impact of the ipsilateral NTO was increased as it was moved closer to the participants, as suggested by Tresilian (1998), into positions that were of greater obstruction to the hand and arm. Participants in the ipsilateral and contralateral NTO groups appear to have approached the task in a different manner. When the NTO was contralateral, the risk of collision was low and participants developed a set reach plan that was repeated nearly identically for each NTO position. When the NTO was ipsilateral, however, the intrusiveness of the NTOs appears to have forced participants to appraise the scene to develop a plan for each trial that would bring the hand and arm around the NTO to the target. This difference in strategies may explain why participants in the ipsilateral NTO group produced more "efficient" reach movements, with shorter horizontal path lengths, in the control condition than those produced by the contralateral group. The trial-by-trial appraisal of the scene by participants in the ipsilateral NTO group appears to have produced a benefit in performance. Even though the differences do not reach significance in our other measures, this same trend is present.

When the NTO was contralateral, final grasp and gaze positions shifted to the right as the target became wider and shorter. This pattern of results replicates previous research where NTOs were never present (Desanghere & Marotta, 2011; Paulun et al., 2013) and suggests that the shift rightward in grasp and gaze were not due to contralateral NTOs. In fact, the only measure that showed a contralateral NTO effect on performance was horizontal path length. A contralateral NTO at the closest location (1) produced greater path lengths than the no-NTO control condition and the farthest, "less obtrusive," inner position (5). It should be noted that the necessity to run the current study as a split-plot design, due to the large number of potential NTO positions, meant that participants reaching under the contralateral NTO condition never saw the NTOs in the ipsilateral "obstacle" position. It is possible that we may have observed more avoidance of contralateral NTOs if participants had previously had to avoid that same NTO when it was positioned on the ipsilateral side. Nevertheless, our findings are in agreement with previous work that ipsilateral NTOs have a significant larger impact on reach performance than contralateral NTOs (Dean & Brüwer, 1994; Chapman & Goodale (2008, 2010).

Our results suggest that gaze was directed toward the target and anchored there nearly exclusively, rather than being directed toward the NTOs. Future investigations that manipulate the *saliency* of the NTOs (through size, shape, similarity to target, colour, etc.) may find that more robust/obtrusive/dangerous NTOs do a better job at drawing fixation. The measures of reach mechanics appear to be more sensitive to the attentional relevance of an NTO than were measures of gaze. The "push" from ipsilateral NTOs was of greater magnitude for grasp location than for fixation and when looking at the difference between grasp and final fixation locations, the most invasive positions pushed grasp further to the left from the final fixation, whereas the final fixation location was not as greatly altered by NTO position. While the motor system needs to be sensitive to changes in the environment in order to accurately execute the reach; the eye is never at risk of colliding with the NTO and therefore can afford to be less sensitive to the layout of the reaching space. As a consequence, the motor system may accomplish path planning using exclusively peripheral vision (Chapman & Goodale, 2008).

Résumé

Des recherches antérieures ont étudié les effets d'objets non cibles sur les trajectoires de portée mais leurs effets sur la coordination oculo-manuelle restent à être déterminés. La présente enquête a utilisé un paradigme de coordination oculo-manuelle, où une tâche de saisie et de portée était effectuée en présence d'un objet non cible placé exclusivement dans l'espace de travail de droite ou de gauche de chaque participant droitier. Les objets non cibles variaient dans leur proximité avec le sujet et la trajectoire de portée, entre la position de départ de la main et l'objet cible de la portée. Une condition de contrôle, où seulement la cible était présente, était également incluse. Lorsqu'un objet non-cible a été présenté sur la droite (en position ipsilatérale par rapport à la main effectuant la portée), la saisie et le regard finaux se sont portés sur la cible, les déplaçant vers la gauche, c'est-à-dire loin de l'« obstacle ». L'impact de l'objet non cible ipsilatéral augmentait à mesure qu'il se rapprochait du participant à des positions qui constituaient un obstacle plus important pour la main et le bras. En revanche, lorsqu'un objet non cible était controlatéral, le risque de collision était faible et les participants ont élaboré un plan de portée défini qui était répété de manière quasi-identique pour chaque position d'objet non cible controlatérale. Nos résultats indiquent également que le « caractère envahissant » des positions d'objets non cibles avaient un effet plus grand sur la saisie que sur la position du regard – démontrant ainsi comment l'arrangement de désordre dans un environnement peut affecter différémment le regard et la saisie quand on essaie d'atteindre un objet.

Mots-clés : vision, saisie, perception et action, coordination oculo-manuelle, attention.

References

Bulloch, M. C., Prime, S. L., & Marotta, J. J. (2015). Anticipatory gaze strategies when grasping moving objects. *Experimental Brain Research, 233,* 3413–3423. http://dx.doi.org/10.1007/s00221-015-4413-7

Chapman, C. S., & Goodale, M. A. (2008). Missing in action: The effect of obstacle position and size on avoidance while reaching. *Experimental Brain Research, 191,* 83–97. http://dx.doi.org/10.1007/s00221-008-1499-1

Chapman, C. S., & Goodale, M. A. (2010). Seeing all the obstacles in your way: The effect of visual feedback and visual feedback schedule on obstacle avoidance while reaching. *Experimental Brain Research, 202,* 363–375. http://dx.doi.org/10.1007/s00221-009-2140-7

Dean, J., & Brüwer, M. (1994). Control of human arm movements in two dimensions: Paths and joint control in avoiding simple linear obstacles. *Experimental Brain Research, 97,* 497–514. http://dx.doi.org/10.1007/BF00241544

Desanghere, L., & Marotta, J. J. (2011). "Graspability" of objects affects gaze patterns during perception and action tasks. *Experimental Brain Research, 212,* 177–187. http://dx.doi.org/10.1007/s00221-011-2716-x

Desanghere, L., & Marotta, J. J. (2015). The influence of object shape and centre of mass on grasp and fixation locations. *Frontiers in Psychology, 6,* 1537. http://dx.doi.org/10.3389/fpsyg.2015.01537

Efron, R. (1968). What is visual perception? *Boston Studies in Philosophy of Science, 4,* 173.

Hayhoe, M. (2000). Vision using routines: A functional account of vision. *Visual Cognition, 7,* 43–64. http://dx.doi.org/10.1080/135062800394676

Johansson, R. S., Westling, G., Bäckström, A., & Flanagan, J. R. (2001). Eye-hand coordination in object manipulation. *The Journal of Neuroscience, 21,* 6917–6932.

Mon-Williams, M., Tresilian, J. R., Coppard, V. L., & Carson, R. G. (2001). The effect of obstacle position on reach-to-grasp movements. *Experimental Brain Research, 137,* 497–501. http://dx.doi.org/10.1007/s002210100684

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia, 9,* 97–113. http://dx.doi.org/10.1016/0028-3932(71)90067-4

Paulun, V., Kleinholdermann, U., Gegenfurtner, K., Smeets, J., & Brenner, E. (2013). How to choose where to place the fingers when grasping a small bar: Effects of object weight and movement distance on grasp point selection. *Journal of Vision, 13,* 337. http://dx.doi.org/10.1167/13.9.337

Prime, S. L., & Marotta, J. J. (2013). Gaze strategies during visually-guided versus memory-guided grasping. *Experimental Brain Research, 225,* 291–305. http://dx.doi.org/10.1007/s00221-012-3358-3

Salvucci, D. D., & Goldberg, J. H. (2000). Identifying fixations and saccades in eye-tracking protocols. In A. T. Duchowski (Ed.), *Proceedings of the eye tracking research and applications symposium* (pp. 71–78). New York, NY: ACM Press.

Tipper, S., Howard, L., & Jackson, S. (1997). Selective reaching to grasp: Evidence for distractor interference effects. *Visual Cognition, 4,* 1–38. http://dx.doi.org/10.1080/713756749

Tresilian, J. R. (1998). Attention in action or obstruction of movement? A kinematic analysis of avoidance behavior in prehension. *Experimental Brain Research, 120,* 352–368. http://dx.doi.org/10.1007/s002210050409

Verheij, R., Brenner, E., & Smeets, J. B. (2014). The influence of target object shape on maximum grip aperture in human grasping movements. *Experimental Brain Research, 232,* 3569–3578. http://dx.doi.org/10.1007/s00221-014-4046-2

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